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FOR

PERPENDICULAR POLE TIP AND METHOD OF

FABRICATION

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PERPENDICULAR POLE TIP AND METHOD OF FABRICATION

FIELD OF THE INVENTION

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The present invention relates to a method of patterning magnetic structures, and more particularly, this invention relates to a method of patterning particularly useful for perpendicular head fabrication.

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BACKGROUND OF THE INVENTION

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In a typical head, an inductive write head includes a coil layer embedded in first, second and third insulation layers (insulation stack), the insulation stack being located between first and second pole piece layers. A gap is formed between the first and second pole piece layers by a gap layer at an air bearing surface (ABS) of the write head. The pole piece layers are connected at a back gap. Currents are conducted through the coil layer, which produce magnetic fields in the pole pieces. The magnetic fields fringe across the gap at the ABS for the purpose of writing bits of magnetic field information in tracks on moving media, such as in circular tracks on a rotating magnetic disk or longitudinal tracks on a moving magnetic tape.

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The second pole piece layer has a pole tip portion which extends from the ABS to a flare point and a yoke portion which extends from the flare point to the back gap. The

flare point is where the second pole piece begins to widen (flare) to form the yoke. The placement of the flare point directly affects the magnitude of the magnetic field produced to write information on the recording medium. Since magnetic flux decays as it travels down the length of the narrow second pole tip, shortening the second pole tip will
5 increase the flux reaching the recording media. Therefore, performance can be optimized by aggressively placing the flare point close to the ABS.

FIG. 1 illustrates, schematically, a conventional recording medium such as used with conventional magnetic disc recording systems. This medium is utilized for recording magnetic impulses in or parallel to the plane of the medium itself. The recording medium,
10 a recording disc in this instance, comprises basically a supporting substrate **100** of a suitable non-magnetic material such as glass, with an overlying coating **102** of a suitable and conventional magnetic layer.

FIG. 2 shows the operative relationship between a conventional recording/playback head **104**, which may preferably be a thin film head, and a
15 conventional recording medium, such as that of FIG. 1.

FIG. 3 illustrates schematically the orientation of magnetic impulses substantially perpendicular to the surface of the recording medium. For such perpendicular recording the medium includes an under layer **302** of a material having a high magnetic permeability. This under layer **302** is then provided with an overlying coating **304** of
20 magnetic material preferably having a high coercivity relative to the under layer **302**.

Two embodiments of storage systems with perpendicular heads **300** are illustrated in FIGS. 3 and 4 (not drawn to scale). The recording medium illustrated in FIG. 4 includes both the high permeability under layer **302** and the overlying coating **304** of

magnetic material described with respect to FIG. 3 above. However, both of these layers **302** and **304** are shown applied to a suitable substrate **306**.

By this structure the magnetic lines of flux extending between the poles of the recording head loop into and out of the outer surface of the recording medium coating with the high permeability under layer of the recording medium causing the lines of flux to pass through the coating in a direction generally perpendicular to the surface of the medium to record information in the magnetically hard coating of the medium in the form of magnetic impulses having their axes of magnetization substantially perpendicular to the surface of the medium. The flux is channeled by the soft underlying coating **302** back to the return layer (P1) of the head **300**.

FIG. 5 illustrates a similar structure in which the substrate **306** carries the layers **302** and **304** on each of its two opposed sides, with suitable recording heads **300** positioned adjacent the outer surface of the magnetic coating **304** on each side of the medium.

As perpendicular heads become smaller to accommodate ever increasing data density, fabrication processes must be adapted to properly create the fragile structures that will ultimately form the head. Current fabrication methods are not capable of adequately and consistently forming pole tips to the scale and tolerances required for modern disk drives.

One proposed process uses a patterned photoresist mask **602** formed above a pole tip layer of magnetic material **604** and a layer of nonmagnetic material **606** such as Al_2O_3 . The structure **600** is shown in FIG. 6. The structure **600** is milled to form the pole tip from the layer of magnetic material **604**. The resulting structure **700** is shown in FIG.

7. While the process forms a pole tip **702** with the desired tapered cross-section, there are several disadvantages. First, this process does not scale easily below 0.25 μm , which is necessary for high data density drives. Second, the resist **602** does not have an acceptable mill resistance, i.e., too much of the mask **602** is consumed in the mill process. The result is that the pole tip is sometimes damaged by the milling. Third, removal of the resist **602** is necessary at the pole tip **702** without knocking over or destroying the pole tip **702**. However, milling inherently produces redeposition **704**, which tends to form on the sides of the resist **602**, and may even encapsulate the resist. This redeposition makes removal of the resist **602** more difficult, as solvent has a harder time reaching the resist-pole tip interface. If any resist **602** remains coupled to the pole tip **702**, attempted removal of the resist **602** tends to tip the pole tip **702** over. Further, some of the resist **602** may be entirely encapsulated by the redeposition. This is unacceptable, as having a layer of soft polymer (resist) at the ABS causes hard disk drive tribology issues, i.e., head-disk interface problems such as wear, water uptake, swelling, etc. Rather, it is desirable to have only hard materials at the ABS.

Another proposed process uses an alumina hard mask layer **802** above a pole tip layer **804**. Instead of photoresist, a layer of NiFe (nonmagnetic) **806** is plated on top of the hard mask layer **802** and trimmed and notched to form the structure **800** shown in FIG. 8. Then, the structure **800** is milled to form the pole tip **902**, as shown in FIG. 9. This process avoids having to remove photoresist, but the extended milling required to mill through the layer of NiFe **806** and alumina hard mask layer **802** create cavities adjacent to the pole tip **902**. Thus, the desired tapered shape of the pole tip **902** is difficult to achieve. Further, if further processing is to be performed above the pole tip **902**, the

layer of NiFe 806 and possibly the alumina hard mask layer 802 may need to be removed to reduce the overall head size and provide a smooth surface upon which to add the additional layers. Removal of these layers without damaging the pole tip 902 is difficult.

What is needed is a method of fabricating pole tips of very small scale while
5 overcoming the aforementioned disadvantages.

SUMMARY OF THE INVENTION

The present invention overcomes the disadvantages described above by providing
5 a method of patterning standard and thin film magnetic structures, and that is particularly adapted to perpendicular heads.

A method for forming a magnetic structure, such as a pole tip, includes forming a layer of magnetic material, hereinafter referred to as a pole tip layer. A layer of polyimide precursor material is added above the pole tip layer. The polyimide precursor material is
10 cured to convert at least a substantial portion of the polyimide precursor material to at least one of a polyimide and a polyimide-like material. A silicon-containing resist layer is added above the layer of polyimide precursor material. The resist layer is patterned. The resist layer is also exposed to oxygen plasma for converting the resist into a glass-like material. Exposed portions of the cured polyimide precursor material are removed for
15 exposing portions of the pole tip layer for defining a width of the pole tip. The exposed portions of the pole tip layer are removed for forming a pole tip. Chemical mechanical polishing (CMP) can then be performed to remove any unwanted material remaining above the pole tip.

The exposed portions of the cured polyimide precursor material can be removed
20 by reactive ion etching. The exposed portions of the cured polyimide precursor material can be removed by reactive ion etching with an oxygen-containing plasma. The exposed portions of the pole tip layer can be removed by milling.

Several optional layers can be added. A first layer of material resistant to chemical mechanical polishing can be added above the pole tip layer to protect the pole tip during the CMP. A layer of nonmagnetic material can be added for substantially encapsulating the pole tip for reducing the tendency of the pole tip to tip over during
5 CMP. Also, a second layer of material resistant to chemical mechanical polishing can be added above the layer of nonmagnetic material to further protect the pole tip from CMP damage.

Additional options include alteration of the mask layer where the mask layer contains a layer that is etch resistant to an oxygen-containing plasma. This may include a
10 hard etch mask that is patterned in a separate process.

Using the methods described herein, pole tips and other structures having a width of less than 70 nm can be successfully created.

One such pole tip is a perpendicular pole tip structure, comprising a pole tip layer of magnetic material having a top surface, a bottom surface, and sides extending between
15 the top and bottom surface. Layers of non-magnetic materials surround the layer of magnetic material towards the sides of the pole tip layer. Interface layers are positioned above the non-magnetic material, portions of the interface layers lying along a plane substantially parallel to the top surface of the pole tip layer. Portions of the interface layers taper towards the pole tip layer at a slope that is from about one to about five times
20 a thickness of the pole tip layer, where the thickness of the pole tip layer is defined between the top and bottom surfaces thereof.

In one embodiment, each of the interface layers includes a layer of chemical mechanical polishing resistant material. In another embodiment, a layer of chemical

mechanical polishing resistant material is positioned above the top surface of the pole tip layer.

Other aspects and advantages of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings,
5 illustrate by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as
5 well as the preferred mode of use, reference should be made to the following detailed
description read in conjunction with the accompanying drawings.

FIG. 1 is a schematic representation in section of a recording medium utilizing a
longitudinal recording format.

FIG. 2 is a schematic representation of a conventional magnetic recording head
10 and recording medium combination for longitudinal recording as in FIG. 1.

FIG. 3 is a magnetic recording medium utilizing a perpendicular recording
format.

FIG. 4 is a schematic representation of a recording head and recording medium
combination for perpendicular recording on one side.

15 FIG. 5 is a schematic representation of the recording apparatus of the present
invention, similar to that of FIG. 4, but adapted for recording separately on both sides of
the medium.

FIG. 6 is an ABS view of a structure to be formed into a pole tip according to a
known process.

20 FIG. 7 is an ABS view of the structure of FIG. 6 upon milling.

FIG. 8 is an ABS view of a structure to be formed into a pole tip according to a
known process.

FIG. 9 is an ABS view of the structure of FIG. 8 upon milling.

FIG. 10 is a simplified drawing of a magnetic recording disk drive system.

FIG. 11 is an ABS view of a magnetic structure, not to scale, being formed according to one embodiment of the present invention.

FIG. 12 is an ABS view of the magnetic structure of FIG. 11, not to scale, upon
5 further processing.

FIG. 13 is an ABS view of the magnetic structure of FIG. 12, not to scale, upon further processing.

FIG. 14 is an ABS view of the magnetic structure of FIG. 13, not to scale, upon further processing.

10 FIG. 15 is an ABS view of the magnetic structure of FIG. 14, not to scale, upon further processing.

FIG. 16 is an ABS view of the magnetic structure of FIG. 15, not to scale, upon further processing.

FIG. 17 is an ABS view of a magnetic structure, not to scale, being formed
15 according to one embodiment of the present invention.

FIG. 18 is an ABS view of the magnetic structure of FIG. 17, not to scale, upon further processing.

FIG. 19 is an ABS view of the magnetic structure of FIG. 18, not to scale, upon further processing.

20 FIG. 20 is an ABS view of the magnetic structure of FIG. 19, not to scale, upon further processing.

FIG. 21 is an ABS view of the magnetic structure of FIG. 20, not to scale, upon further processing.

FIG. 22 is an ABS view of the magnetic structure of FIG. 21, not to scale, upon further processing.

FIG. 23 is a chart of experimental data showing actual track widths of pole tips formed by the process described above vs. target track widths.

BEST MODE FOR CARRYING OUT THE INVENTION

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. 10, there is shown a disk drive 1000 embodying the present invention. As shown in FIG. 10, at least one rotatable magnetic disk 1012 is supported on a spindle 1014 and rotated by a disk drive motor 1018. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk 1012.

At least one slider 1013 is positioned near the disk 1012, each slider 1013 supporting one or more magnetic read/write heads 1021. More information regarding such heads 1021 will be set forth hereinafter during reference to the remaining FIGS. As the disks rotate, slider 1013 is moved radially in and out over disk surface 1022 so that heads 1021 may access different tracks of the disk where desired data are recorded. Each slider 1013 is attached to an actuator arm 1019 by way of a suspension 1015. The suspension 1015 provides a slight spring force which biases slider 1013 against the disk surface 1022. Each actuator arm 1019 is attached to an actuator means 1027. The actuator means 1027 as shown in FIG. 10 may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the

coil movements being controlled by the motor current signals supplied by controller
1029.

During operation of the disk storage system, the rotation of disk **1012** generates
an air bearing between slider **1013** and disk surface **1022** which exerts an upward force or
5 lift on the slider. The air bearing thus counter-balances the slight spring force of
suspension **1015** and supports slider **1013** off and slightly above the disk surface by a
small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by
control signals generated by control unit **1029**, such as access control signals and internal
10 clock signals. Typically, control unit **1029** comprises logic control circuits, storage means
and a microprocessor. The control unit **1029** generates control signals to control various
system operations such as drive motor control signals on line **1023** and head position and
seek control signals on line **1028**. The control signals on line **1028** provide the desired
current profiles to optimally move and position slider **1013** to the desired data track on
15 disk **1012**. Read and write signals are communicated to and from read/write heads **1021**
by way of recording channel **1025**.

The above description of a typical magnetic disk storage system, and the
accompanying illustration of FIG. **10** are for representation purposes only. It should be
apparent that disk storage systems may contain a large number of disks and actuators, and
20 each actuator may support a number of sliders.

FIG. **11** is an ABS view of a structure **1100** formed during a process for forming a
magnetic structure such as a perpendicular pole tip. For clarity and ease of understanding,
the following description shall refer to creation of a pole tip, it being understood by one

skilled in the art that the processes can be adapted with little or no modification to form magnetic structures for various uses. It is also assumed that one can form additional poles and coil layers at different points in the process.

As shown in FIG. 11, a magnetic pole tip layer **1102** is formed on a layer of
5 nonmagnetic material **1104** such as Al_2O_3 . The pole tip layer **1102** can be formed of any suitable magnetic material including NiFe, CoFe, laminates, etc.

As depicted in FIG. 12, a layer of a polyimide precursor polymer **1202** is spun onto the structure of FIG. 11. A preferred polyimide precursor polymer is DURIMIDE®, sold by Arch Chemicals Inc., 501 Merritt 7, P.O. Box 5204, Norwalk, CT, 06856-5204,
10 USA. Note that instead of a polyimide precursor polymer, other material that upon curing (e.g., baking) forms a material that is polyimide-like may also be used. For clarity, the remaining discussion shall refer to a polyimide precursor polymer, it being understood that this term includes polymers capable of forming polyimides and polyimide-like materials.

15 The polyimide precursor polymer **1202** is hard baked to cure the polymer **1202**, forming the polyimide or polyimide-like material.

Referring to FIG. 13, to form the desired shape of the cured polyimide precursor polymer **1202**, a silicon-containing resist layer **1302** is added and patterned to allow patterning of the cured polyimide precursor polymer **1202**. Photo-exposable or electron
20 beam exposable Si-containing resists may be used. A preferred Si-containing resist is an e-beam resist such as hydrogen silsesquioxane (HSQ), sold by Dow Corning Corporation, Corporate Center, PO box 994, Midland, MI, 48686-0994, USA.

FIG. 14 is a top down depiction of the structure of FIG. 13. As shown, the e-beam exposes an anchor pad **1402**, a line (pole) **1404**, and another anchor pad **1406**. The anchor pads **1402**, **1406** add stability to the pole **1404** so that it is less likely to tip over during subsequent processing. In addition, the exposed surface (i.e., ABS) of the slider **1409**
5 should coincide with the pole.

The Si-containing resist **1302** is exposed to an oxygen plasma, which converts the resist **1302** to a material that is like glass, e.g., SiOx. The SiOx mask is then used as a hard mask to RIE with an oxygen-containing plasma (e.g., CO₂ plasma) to form the polyimide stack, as shown in FIG. 15. In general terms, the resulting structure is a
10 patterned polyimide layer and a Si-containing mask on top of a polyimide layer.

The structure of FIG. 15 is milled, such as by ion beam milling, to remove the exposed portions of the pole tip layer **1102**, thereby forming the pole tip **1502**. The resulting structure is shown in FIG. 16. Subsequent processing, described in more detail below, is used to remove the polyimide layer and any remaining resist.

15 Note that in the above process, as well as in the subsequently discussed processes, additional layers may be added to the structures if desired.

In a preferred process, a pole tip layer **1102** is formed on a layer of nonmagnetic material **1104** as above. As shown in FIG. 17, the pole tip layer **1102** is coated with a first chemical mechanical polishing (CMP)-resistant layer **1702** prior to addition of the
20 polyimide precursor polymer **1202**. The CMP-resistant layer **1702** is hard such that it is more resistant to removal by CMP than other surrounding materials. The CMP-resistant layer **1702** is preferably formed of diamond-like carbon (DLC) of a thickness greater than about 50 Å, and ideally in the range of about 100-1000Å. A thin layer of an adhesive (not

shown) can be added to the pole tip layer **1102** prior to coating with the CMP resistant layer to aid in adhering the CMP-resistant layer **1702** to the pole tip layer **1102**. For example a layer of Si-containing adhesive having a thickness of about 5-20 Å can be used.

5 Then, the polyimide precursor polymer **1202** and Si-containing resist **1302** are formed, cured and patterned as described above, resulting in the structure shown in FIG. **18**.

 The structure of FIG. **18** is milled to define the pole tip **1802**, which is shown in FIG. **19**.

10 The actual milling process will vary depending on the type of tool selected, gas used, ion energies, etc. The mill pattern may also vary. For example, the wafer can be rotated in one direction, sweep milling (oscillating rotation) can be performed, etc. Preferably the milling is performed at alternating mill angles of less than 25 degrees from normal to remove the exposed portions of the pole tip layer **1102** and greater than 50
15 degrees from normal to remove redeposition, where normal is defined as perpendicular to the plane of the layers of materials and parallel to the ABS. The structure is preferably milled such that the pole tip **1802** has a certain amount of beveling to form a trapezoidal shape. The trapezoidal shape reduces the likelihood of writing to adjacent tracks, translating into a lower error rate. The inventors have found that alternating milling at
20 about 10 degrees and at about 70 degrees from normal provide a beveled pole tip **1802** without substantial amounts of redeposition.

 As shown in FIG. **20**, after milling, the entire surface is coated with a nonmagnetic material **2002**, preferably alumina (e.g., AlOx), by full film deposition. The

entire thickness of the alumina layer **2002** is preferably about as thick as or thicker than the thickness of the pole tip **1802**. Making the alumina layer **2002** as thick as or thicker than the pole tip **1802** prevents the pole tip **1802** from delaminating from its underlayer and/or tipping over during later CMP, as well as aiding in the prevention of CMP damage to the pole tip **1802** itself. The thickness of alumina refill **2002** is preferably in the range of about 100-500% the thickness of the pole tip **1802**. More than 500% can result in the subsequent CMP not being able to remove enough material to expose the resist to solvent.

On top of the AlOx fill, a second CMP-resistant layer **2102** (e.g., DLC), or interface layer, is deposited full film onto the structure, as depicted in FIG. **21**. The thickness of the second CMP-resistant layer **2102** may or may not be the same as that of the first CMP-resistant layer **1702**. A preferred thickness of the second CMP-resistant layer **2102** should be greater than about 50 Å, and is ideally in the range of about 100-1000Å.

The upper surface of the second CMP-resistant layer **2102** is preferably located at or above the plane of the upper surface of the pole tip **1802** to prevent the pole tip **1802** from delaminating from its underlayer and/or tipping over during later CMP, as well as aiding in the prevention of CMP of the pole tip **1802** itself.

The structure shown in FIG. **21** is polished such as by CMP to create the structure shown in FIG. **22**. The amount of polishing is important, as it is desirable to avoid any CMP of the pole tip material to avoid damage to the pole tip **1802**, which could result in the pole tip **1802** having a variable track width. However, too little CMP may result in not breaking open the anchor pad to allow solvent to reach the remaining polyimide-like

layer **1202**. Also, some of the resist may remain encapsulated by material redeposited during the milling. Too much CMP may result in damaging the pole tip **1802**. Thus, the structure is preferably polished down to or into the first CMP-resistant layer **1702**, but not remove the layer **1702**.

5 The preferred CMP process is very gentle. In one embodiment, the wafer is rotated one or more times for a duration of less than about a minute, and preferably less than 30 seconds, under the CMP pad at a pressure of less than about 5 psi and in a nonreactive slurry (e.g., a slurry that does not readily etch the pole tip material) such as CABO-SPERSE® SC1 available from Cabot Microelectronics, 870 N. Commons Drive,
10 Aurora, IL 60504, USA.

Solvent is applied to remove any remaining resist exposed by the CMP. The carbons can be removed with an oxygen plasma, leaving an essentially (but not necessarily perfectly) coplanar surface of alumina **2002**, the pole tip **1802** (e.g., NiFe), and alumina **2002**.

15 Because the alumina refill **2002** is thicker than the pole tip **1802**, portions of the alumina refill **2002** adjacent the pole tip will tend to taper towards the pole tip **1802** at a slope that is from about one to about five times a thickness of the pole tip **1802** after the polish process.

FIG. 22 also shows that the completed pole tip contains a transition length **2202**
20 consisting of the non-magnetic material **1202**. It should also be noted that it is likely that the plane **2208** defined substantially away from the pole will ideally be inside the field CMP-resistant layer **2102**. This plane **2208** will be slightly higher than the plane **2222**

defined by the top surface of the pole tip 1102. Therefore, it is not unexpected that this creates a transition 2202 between the two aforementioned planes 2208, 2222.

Additional layers can then be added for forming additional portions of the structure. Because the upper surface of the formed structure is essentially flat, the
5 additional layers will be more easily formed.

The process described herein has been used to form pole tips of about 69 nm wide, and can be used to form pole tips of even smaller widths.

Examples

10 FIG. 23 is a chart 2300 of experimental data showing actual track widths of pole tips formed by the process described above vs. target track widths. As shown, the actual track widths are nearly on target. For example, when the target track width created in the hard mask layer 1302 was 150 nm, the actual track width was about 160 nm. When the target track width was 100 nm, the actual track width was about 100 nm ($\pm 10\%$). What is
15 also mentioned in FIG. 23 is various thicknesses of a “clean up” mill. This simply was to illustrate that the mill time at high angle (to remove redeposition from the milling) influences the track width and the amount of bevel angle that is found in the final pole tip 1102. The “clean up” mill of longer time is equivalent of removing greater amounts of NiFe.

20 While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-

described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.